METHOD AND DEVICE FOR GENERATING A SINGLE-USE
FINANCIAL ACCOUNT NUMBER

Ins A 1 7.

BACKGROUND OF THE INVENTION

This invention relates to a method and a device for
generating a single-use, transaction-specific financial
account number, thereby providing a high level of security
for financial transactions, particularly credit card
transactions.

There are over 500 million general purpose, retail, oil and
other credit card accounts in the United States (hereafter
called "cards"). Worldwide the figure is almost 1 billion
such cards. Typically, each authorized user of an account is
issued a credit card: a physical plastic object with an
embossed account number and cardholder name appearing on its
face. Anti-counterfeiting indicia, such as holograms,
photographs or signatures, may also appear on the card to
discourage wrongful usage.

Since the credit card number is unchanging, there is a risk
of fraudulent use by anyone who steals the number. The key
element of defense against a fraudulent user impersonating
the authentic cardholder is signature verification. A
signature area appears on the back of most cards, and when a
person receives a new credit card, he is instructed to sign
his name on the back of the card. A merchant who accepts the
card will then be able to compare the signature specimen that

appears on the back of the card to the signature on the sales
draft signed by the consumer at the time of purchase. In
some cases, the merchant may also ask for photo ID before
accepting the card or as a method of checking that the
signatures are for the person whose name appears on the face
of the card.

In addition to examining the signature on the card, most
merchants who accept credit cards use a small device known as
an authorization terminal. The authorization terminal is
capable of reading information disposed on a magnetic stripe
located on the back of the credit card. In some cases, this
stripe also contains other difficult-to-counterfeit
information. To process a credit card purchase, the merchant
passes the card through the magnetic stripe reader of the
terminal and enters the amount of the purchase. The
information is then sent by the device over a phone or
wireless connection to a central database for account number
verification and purchase authorization. A card that has
been reported lost or stolen is declined. If magnetic
stripes on credit cards become damaged and unreadable, the
authorization terminal permits manual entry of the credit
card number as it appears embossed on the face of the card.

With the dramatic growth of direct marketing, an increasing
share of all card purchases are being made without the
physical presentation of the card to the selling merchant.
Instead, the consumer simply relays the card number to the
merchant, and the merchant enters the card number into a
computer terminal which is also designed to handle the order
processing function. As electronic commerce grows over the
next decade, the percentage of such remote, non-face-to-face
purchases can be expected to grow. This poses an
increasingly acute problem for the entire credit card system,

since credit card numbers are highly insecure.

To protect against thieves fraudulently creating credit card numbers and then using them for remote purchasing, a check-digit algorithm is typically employed for credit card account numbers which makes it comparatively difficult (approximately 1 chance in 500,000) to pick a random 16-digit number that is also a valid credit card account number. In addition, since not every valid credit card account number is currently in use, simply making up a valid number is, in itself, not enough to get an authorization code from the central authorizing network. In addition to passing the check-digit test, a bank must have issued that number to an active customer.

To further help combat mail-order based credit card fraud, both Visa and MasterCard have deployed databases that allow a merchant to verify that a given credit card account number is connected to a specific billing address. Visa calls this service the Address Verification Service. The theory behind the service is that a thief (for example, a dishonest restaurant waiter) might be able to use a credit card receipt slip to steal an active account number, but if he tries to use that number for a mail order purchase he would not know the correct address associated with that number. Even if a thief were to obtain the cardholder's address, this service can allow a merchant to compare the shipping address of the catalog order to the current billing address for that account number and thus possibly identify any suspicious activity.

Currently, credit cards also incorporate an expiration date after which they are no longer valid. These dates are typically one to two years after the card is issued. The reason for an expiration date is to reduce the issuing bank's

risk of cards being presented after an account is closed.
Since the expiration date is an absolute indication of
whether or not to accept a card, an old card that is lost or
misplaced eventually expires with minimal risk that it will
be found and used improperly.

In addition, credit card information and transaction
information may be encrypted using well known encryption
schemes like RSA's public key cryptography. For example, SET
is a joint Visa/MasterCard standard for encrypting credit
card numbers transmitted over the Internet.

In spite of these safeguards, credit card security is
vulnerable to a number of attacks by unscrupulous persons.
Some examples of these attacks are as follows:

a) Theft of cards: Any conventional credit card which is
stolen can be misused, either at a merchant's establishment
by forging the signature on the card onto a sales slip, or by
ordering merchandise or services remotely.

b) "Sniffing:" Credit card transaction information being
transmitted over public networks can possibly be intercepted
and captured or "sniffed." The sniffed information can then
be used to create counterfeit cards and/or order goods and
services. For example, if a hacker were to break the SET
encryption scheme, the hacker could sniff out credit card
numbers and misuse them. Re-submission of the sniffed
encrypted credit card numbers to the same merchant is known
as "replay."

A large-scale attack on credit-card number security would
threaten the entire credit card system. For example, if
someone were to steal 1 million active credit card account

numbers, and were also able to steal the billing addresses to which those cards were issued, the entire credit card system would be threatened. At the very least, mail order sales might have to be suspended until new safeguards were put in place. At worst, a flood of counterfeit cards, with correct account numbers and valid names embossed on their faces, could be created.,

With the advent of almost instantaneous worldwide money transfers, a band of organized thieves could clear hundreds of millions or even billions of dollars of charges through the authorization system and then wire that money to a safe haven before cardholders suspected that their cards had been charged an unauthorized amount. If the theft also involved data revealing each account's unused available credit line, such criminal activity might be even harder to detect before it was too late to rescind the wire transfers of stolen money.

Cards which store information, as opposed to merely having embossed numbers, are known in the art. Such "smart cards" are becoming increasingly common. These cards contain a small microprocessor capable of storing data in a secure fashion and of performing computer operations on such data. Smart cards may have built-in small numeric display screens. In particular, smart cards used for distribution of cryptographic keys, display keys on their display screens.

Smart cards are used to authenticate card users and to authenticate the card/user combination to a third party. These cards are also used for controlling access to computer systems and databases and entry into secure areas. Northern Telecom offers a credit card sized smart card called Entrust which contains a microchip that stores encoded, private keys.

Hardware tokens such as Security Dynamics' SecurID card use a "time synchronous methodology" to produce passwords every 30 seconds.

Wire transfer calculator-style devices are also known in the art. Such devices are the size of a credit card and contain a tamper-resistant, "secure perimeter" within which is disposed a clock and a cryptoprocessor. These devices also have a small LCD alpha-numeric display screen and a numeric keypad for data entry.

A number of security devices and methods involving credit cards have been disclosed. For example, U.S. Patent No. 5,311,594, "Fraud Protection For Card Transactions," describes a challenge-response method for fraud protection wherein credit card holders are authenticated based on their responses to randomly asked questions like their mother's phone number, their graduation year, birth date, etc. The responses are checked against prestored information in a database.

U.S. Patent No. 5,457,747, "Anti-Fraud Verification System Using a Data Card," describes a biometric system for deterring credit card fraud. Credit cards have two magnetic stripes, one that has been permanently encoded with the card holder's biometric information and one that an ATM can write onto. To use the card, the card holder supplies the same biometric information at a verification terminal. The terminal checks the biometric information supplied by the card holder against that recorded on the magnetic stripe. If the biometrics match, the terminal will write a transaction authorization onto the magnetic stripe.

U.S. Patent No. 5,485,519, "Enhanced Security For a Secure

Token Code," describes a method for enhancing security for a
private key stored in a smart card. A user input PIN is
combined algorithmically with a code resident in the smart
card to produce the private key. The private key is not
stored in the smart card except for short intervals when the
card is actually being used by an authorized user who has
input his PIN.

SUMMARY OF THE INVENTION

This invention provides a method and a device to facilitate
secure electronic commerce, secure remote credit card
purchases, and secure conventional credit card purchases
wherein the customer is assured that the merchant or an
intercepting third party cannot misuse any credit card
information.

According to one aspect of our invention, a method for
generating a single-use financial account identifier is
provided which includes the steps of accessing a first data
element specific to an account; accessing a second data
element including transaction-specific data; and combining
the first data element and the second data element to produce
the single-use financial account identifier.

According to another aspect of our invention, a device for
facilitating credit transactions is provided which includes a
processing unit including a cryptographic processor. The
device also includes an input unit connected to the
processing unit for inputting information thereto, and a
display unit connected to the processing unit for displaying
a processing result. In addition, the device includes a
memory device connected to the processing unit. The memory

device contains a private cryptographic key, a first data
element, a second data element and a program adapted to be
executed by the processing unit. In accordance with the
program, the processing unit encrypts the first data element
using the private cryptographic key and the second data
element, modifies the second data element, combines the
encrypted first data element and the second data element to
generate a single-use financial account identifier, and
displays the single-use financial account identifier using
the display unit.

According to a further aspect of our invention, a system for
verifying a financial account identifier is provided which
includes a processing unit including a cryptographic
processor. The system also includes a communications unit,
connected to said processing unit, for transmitting and
receiving information regarding the financial account
identifier, and a memory device. The memory device contains
a private cryptographic key, a first data element, a second
data element and a program adapted to be executed by the
processing unit. In accordance with the program, the
processing unit receives a single-use financial account
identifier, extracts therefrom a third data element and a
fourth data element, decrypts the third data element using
the private cryptographic key and the fourth data element,
compares the decrypted third data element with the first data
element in a first comparison, compares the fourth data
element with the second data element in a second comparison,
and verifies the received financial account identifier in
accordance with the first comparison and the second
comparison.

According to still another aspect of our invention, a method
for providing a single-use financial account identifier

includes the steps of: providing a memory storing data
representing a plurality of predetermined single-use
financial account identifiers, data representing a status for
each single-use financial account identifier, and data
representing a pointer to one of the single-use financial
account identifiers; identifying the single-use financial
account identifier based on the pointer data; and
transmitting a signal to an output device to present the
single-use financial account identifier.

According to a further aspect of our invention, a device for
providing a single-use financial account identifier is
provided which includes a memory, an output device and a
processor coupled to the memory and to the output device.
The memory stores data representing a plurality of
predetermined single-use financial account identifiers, data
representing a status for each of the predetermined
single-use financial account identifiers, and data
representing a pointer to one of the predetermined single-use
financial account identifiers. The output device presents
the single-use financial account identifier. The processor
is configured to identify the single-use financial account
identifier based on the data representing a pointer, and to
transmit a signal to the output device to present the
single-use financial account identifier.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of the hand-held smart card
device in accordance with the present invention.

Figure 2 is a block diagram of the device's central
processor.

Figure 3A is a block diagram of the overall system of the present invention.

Figure 3B is a flowchart showing the basic method of the present invention.

Figure 4 is a block diagram of the credit card issuer's central processor, with databases as used in accordance with the first embodiment of the invention.

Figure 5 shows in tabular form the credit card account holder database.

Figure 6 shows in tabular form the account holder secret key database.

Figure 7 shows in tabular form the credit card transaction database according to the first embodiment of the invention.

Figure 8 is a flowchart describing an encryption scheme used to generate a single-use credit card number in accordance with the first embodiment of the invention.

Figures 9A and 9B are connected flowcharts describing the operations performed by the central processor of a credit card issuer to generate an authorization code, in accordance with the first embodiment of the invention.

Figure 10 is a flowchart describing the operations performed by a device to generate and display a single-use credit card number, in accordance with a second embodiment of the invention.

Figures 11A and 11B are connected flowcharts describing the operations performed by a credit card issuer's central controller to generate an authorization code, in accordance with the second embodiment of the invention.

Figure 12 is a block diagram of the credit card issuer's central processor, with databases as used in accordance with the second embodiment of the invention.

Figure 13 shows in tabular form the credit card number database.

Figure 14 shows in tabular form the credit card transaction database according to the second embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 is a schematic diagram of a device 100 for generating a single-use credit card number in accordance with this invention. This device is preferably a smart card, hereinafter referred to as the "device." The device has a keypad 103, a display screen 102, a memory 104 and a central processor 101. Memory 104 contains a key 601, and CPU 101 contains a cryptographic processor. The device may be activated through the input of a unique cardholder identifier such as a personal identification number (PIN) through the keypad 103. Alternatively, the device may include a biometric interface 105, and be activated by the input of a suitable biometric record such as the cardholder's fingerprint.

Figure 2 is a schematic diagram showing further details of the central processor 101 of device 100. The central

processor 101 includes a microprocessor 201. The
microprocessor 201 is connected to a clock 202, a random-
access memory (RAM) 203, a read-only memory (ROM) 204, and a
cryptographic processor 205. In addition, the microprocessor
201 is connected to the keypad 103 for receiving input from
the user and to the display 102 for prompting the user or
displaying information.

Figure 3A is a schematic diagram of the environment in which
the method and system of the present invention are used. A
cardholder 301, wishing to purchase goods or services from a
merchant 302 (not necessarily in person), transmits a single-
use credit card number 300 to the merchant. The merchant 302
transmits the single-use credit card number 300 to a credit
card issuer 303. The credit card issuer 303 returns an
authorization 310 to the merchant, based on which the
merchant delivers the desired goods or services 320 to the
cardholder.

Figure 3B shows the steps of the basic method of using the
device in accordance with the present invention. To purchase
goods or services in person, via telephone or via the
Internet, cardholder 301 uses device 100 to generate a
transaction-specific, single-use credit card number. The
cardholder first inputs his PIN or biometric data to access
the device (step 351). If access is granted, the device
responds by querying the cardholder on display 102 whether it
should generate a single-use credit card number (step 355).
The cardholder responds by requesting generation of a credit
card number (for example, by keying "YES"). He may
optionally be asked to enter the amount of the purchase in
step 356 or a merchant code number provided by the merchant.
This number could be only a few digits long since it does
not have to be unique to each merchant.

The device then generates a single-use credit card number
(step 360); details of the card number generation are
explained below. The number is unique for the specific input
variables set by the cardholder or by the device. It may
also be unique to the specific date and time to avoid
so-called "replay" attacks for that card at that merchant
with that exact purchase amount. The single-use credit card
number is preferably a 16-digit number that can be recognized
as a conventional credit card number.

The cardholder transmits the single-use number to the
merchant (step 361), and the merchant enters the single-use
number into an authorization terminal connected to a central
credit card processing system maintained by the credit card
issuer (step 362). A check digit may be included in the
number to prevent the incorrect keying of the number. The
number is sent to the credit card processing system for
authorization (step 363). The central system processor maps
the single-use credit card number onto a conventional credit
card account and determines whether the transaction is
authorized (step 380); if so, the central system returns an
authorization code for display on the merchant's
authorization terminal (step 390); if not, the central system
transmits an authorization failed message for display on the
merchant's authorization terminal (step 395).

Throughout this discussion, the term "credit card number"
refers to a number that is used only one time to perform a
specific transaction, and is generated using the device 100;
in contrast, the term "account number" refers to an
unchanging identifier for the cardholder which is stored in a
database maintained by the card issuer.

First Embodiment (Device Private Key Encryption)

In this embodiment, the single-use credit card number is generated by the device cryptoprocessor 205, using a private key 601 stored in the device memory 104 (preferably the ROM 204). The encryption data changes with each use of the card, so that the single-use encrypted credit card number is different for each transaction. This credit card number is distinct from the unchanging account number identifying the particular cardholder. It should be noted that knowledge of the account number does not allow an attacker to generate a valid single-use credit card number.

When the single-use credit card number is transmitted to a merchant, the merchant passes the number to the card issuer's central processor for authorization. The central processor decrypts the number based on a known algorithm, determines the true account number, and either authorizes or denies the charge.

Figure 4 is a schematic diagram of the credit card issuer's central processor 400. The processor includes a central processing unit (CPU) 401. The CPU is connected to a clock 402, a random-access memory (RAM) 403, a read-only memory (ROM) 404, a cryptographic processor 405, and a communication port 406 for communication with the merchant's central processor. In addition, the CPU 401 is connected to a storage device 410, which includes a credit card account holder database 411, a credit card account private key database 412, and a credit card transaction database 413.

The data structure of the credit card account holder database 411 is shown in Figure 5. Each record in the database

includes the cardholder account number 501, the cardholder's name 502, address 503 and telephone number 504, the original credit line 505 associated with the account, the amount of credit currently available (available credit line 506), and the expiration date 507.

Figure 6 shows the fields of the credit card account private key database 412. Each entry of this database has the cardholder private key 601 and the associated cardholder account number 501. The private key is thus stored in both the device memory 104 and the database 412. An additional secret piece of information, called a "nonce" 602, is associated with the account number. The nonce is also stored in the device memory 104. The nonce need not be as long as the account number, but should not be easily derived therefrom.

Figure 7 shows the fields of the credit card transaction database 413. Each record of this database corresponds to one transaction using the card, and includes the account number 501, the expiration date 507 of the card, the transaction amount 702, the merchant identification number 703 and an initialization variable 704. The initialization variable 704 is used to ensure that each credit card number is unique to the particular transaction, thereby preventing a "replay" attack.

In this embodiment, the device memory 104 has stored therein the private key 601, the nonce 602, the initialization variable 704 and the account number 501. The initialization variable is set at 0 (zero) when the card is newly issued, and is incremented each time a single-use credit card number is generated.

The cryptography described herein requires binary data. Current credit card numbers are 16-digit decimal numbers. Since 10^{16} is only slightly greater than 2^{53}, nearly every such decimal number may be represented by a 53-digit binary number. Therefore, in the following discussion it will be assumed that the credit card number is a 53-bit number and that it is then converted to a 16-digit decimal number for transmission or display.

A credit card number consists of an m-bit initialization variable (abbreviated IV), an a-bit account number, and an n-bit nonce (abbreviated N), where m+a+n = 53. It should be noted that the nonce may take the place of the check code employed with conventional credit card numbers. If n = 16, then the probability that an attacker can generate a valid credit card number is 1 in 2^n = 65536. The parameter n can be varied to change the probability as desired.

The parameters m and a do not necessarily have to be the same size for all credit card holders. However, m should be large enough for any individual cardholder so that he does not use his credit card more than 2^m times before the card expires. For most credit card holders a value of m = 9 would probably suffice, allowing use of the card 512 times (that is, 5 times a week assuming the card is valid for two years) before it expires.

The steps for generating an encrypted single-use credit card number according to this embodiment are shown in Figure 8. In step 801, the device central processor 101 retrieves the nonce 602 and the initialization variable 704 from the device memory 104. In step 802, the nonce is encrypted using the user's private key K and the IV. Thus

$$C = E_K(N, \ IV)$$

where C represents the encrypted nonce. Both N and C are n-bit values.

The central processor 101 then retrieves the account number from the device memory 104 (step 803). In step 804, the encrypted nonce C, the initialization variable IV, and account number A are concatenated to form an encrypted, single-use credit card number CCN:

CCN = C_IV_A, where _ denotes concatenation.

The initialization variable is incremented and the result is stored in the device memory 104 (step 805):

IV = IV + 1

The resulting credit card number CCN is then displayed on the display screen 102 (step 806) and read, shown or otherwise transmitted to the merchant. The merchant transmits this number to the issuer's central processor 400 for authorization of the transaction.

Figures 9A and 9B show the steps for generating an authorization code for the transaction. In step 901 the issuer's central processor 400 receives the single-use credit card number transmitted by the merchant.

To verify the card number, the credit card issuer's central processor first extracts the encrypted nonce C, the initialization variable IV, and account number A from the credit card number (step 902). The processor then retrieves the extracted account number from the cardholder account database 411 (step 903), and determines whether the account number is valid (step 904). If the account number is not valid, the transaction is aborted (step 905). If the account number is valid, the processor looks up the account number in

the credit card transaction database 413 to determine whether the card holder has previously used the initialization variable IV (step 906). If the cardholder has done so, the transaction is aborted (step 908). If the initialization variable has not been used, the incremented initialization variable is stored in the credit card transaction database 413 (step 908). ,

In step 921, the processor retrieves the card holder's private key K in the private key database 412. The private key K then is used to decrypt the encrypted nonce (step 922). This recovers the original nonce N:

$$N = D_K(C, IV).$$

The decrypted nonce N is compared against the nonce 602 stored in the account private key database 412 (step 923). If they match (step 924) then the credit card number is considered valid; otherwise the transaction is aborted (step 925).

If the card is found to be valid, and if the cardholder's account meets the credit card issuer's approval criteria (step 926), then the issuer's central processor generates an authorization code and transmits the code to the merchant (step 928). If not, then the transaction is aborted (step 927).

Approval criteria are issuer specific and may include, but are not limited to, the following: account must be in good standing (not past due); sufficient credit must be available (some issuers may approve purchases that exceed available credit by a specified margin), the card should not have been reported stolen/lost; and the account should not be closed.

There are two types of ciphers which can be used to encrypt

the data (in this embodiment, the nonce N and initialization variable IV): stream ciphers and block ciphers. Stream ciphers can be used with minor modification so that different initialization variables will result in different ciphertext. The amount of information that must be encrypted in this system is smaller than the blocksize of most block encryption algorithms. However, a modified variant of Cipher Feedback Mode may be used to encrypt small amounts of data and has some additional security features.

Accordingly, one possible encryption method uses a stream cipher. Conventional ciphers use a secret key k to produce a stream of data. The data is then combined with the unencrypted data (e.g. by XORing them together) to produce the encrypted text. On the other hand, to encrypt an n-bit value N using initialization variable IV and key k, a stream cipher may be used to generate $n(IV + 1)$ bits of data, with N then combined with the last n bits of the resulting data.

Another way to encrypt the data is to use a block cipher in 1-bit feedback CFB-mode. However, this has some undesirable properties which may allow an attacker to deduce the unencrypted form of encrypted data. While an attacker cannot generate a valid credit card number without knowledge of the user's private key, knowing the user's nonce undermines the security of the account. To avoid this problem the following variant may be used:

    1.   The input of the block cipher I_i consists of the IV concatenated with a $1 - m$ bit shift register (where m is the number of bits in the IV and we are using a 1-bit block cipher). Let S_i be the state of the shift register. Then

$$S_0 = 1$$

and

$$I_0 = IV\_S_0.$$

In fact, $$I_i = IV\_S_i$$ for all i.

2. Bit i of the encrypted data is computed as

$$C_i = f(I_i, k)_0 \oplus P_i$$

where f is the encryption function of the block cipher and $f(I/k)_0$ denotes bit 0 of the encryption of I with key k.

3. The shift register is updated with the ciphertext so that

$$S_{i+1} = (S_i << 1)\_C_i$$

where S << 1 denotes shifting S left 1 bit.

To decrypt the data a nearly identical algorithm is used except that P_i and C_i are reversed. So the second step of the algorithm is all that changes and it becomes:

2′) Bit i of the decrypted data is computed as

$$P_i = f(I_i, k)_0 \oplus C_i$$

where f is the encryption function of the block cipher and $f(I, k)_0$ denotes bit 0 of the encryption of I with key k.

Suitable block ciphers include Triple-DES, IDEA and Blowfish. Suitable stream ciphers include RC4, SEAL and A5. All of these algorithms are discussed in B. Schneier, "Applied Cryptography," John Wiley & Sons, 2d ed. 1996.

The primary defense against replay attacks in this embodiment is checking that the same initialization variable IV is not used twice for any particular account number. When the credit card is issued the internal IV is preferably set to 0. Each time the credit card is used the IV increments by 1. Therefore, as long as the cardholder does not use the credit card more than 2^m times (where the IV is m bits long) the

same initialization variable will never be repeated.
Preferably, the credit card issuer keeps track of the IVs
that the card holder has used. This can be done with a
simple bit array where entry a of the array indicates that IV
a has been used if and only if it is set to 1.

As stated earlier, m = 9 is probably sufficient for most
cardholders. This means that the card issuer needs only keep
track of a 512-bit array for each such credit card. This is
very inexpensive. In addition, if the issuer notices that the
cardholder has nearly exhausted his IVs, then it can issue
the cardholder a new card.

Another attack against this system would be to flood the
central server with bogus credit card numbers (otherwise
known as a denial-of-service attack). One way to make this
attack more difficult is to spread the authorization
processing load across several servers which all have the
capability of verifying a credit card number. If they
receive a valid credit card number, they can coordinate with
the central server to perform the credit card transaction.

Ideally, the load should be spread evenly across several
different servers. A simple way to do this is to set up p
servers and assign each a unique number in the range 0 to
2^p-1. Next, for every credit card number that must be
verified, check a prespecified set of p bits of the credit
card number and assign the verification to the server with
the corresponding number. For example, if the p specified
bits of the credit card number give "14," assign the
verification to the server numbered "14."

For the primary embodiment, there are 2^{53} possible credit card
numbers. A central authority might be established to assign

ranges of account numbers to individual credit card
companies. Once a company receives an r-bit range of account
numbers it may further split the range of numbers up as
desired. Ultimately the issuer should decide upon the size
of the nonce (n bits), the account number (a bits), and the
size of the IV (m bits) so that n+a+m = r. Note that the
account number should include those bits assigned by the
central authority. Also, different card holders can have
different values of n, a, and m even if they receive their
cards from the same credit card company.

After a cardholder's card expires, his account number can be
reused. The next credit card issued with that account number
would use a different nonce and private key. This will
ensure that any credit card numbers generated with the old
credit card will not match any new credit card numbers with
better than random chance.

In an alternative to the present embodiment, timestamps could
be included with the nonce during encryption. Then, credit
cards could be used in conjunction with a clock. When
creating the credit card the credit card issuer should start
the clock at 0 and note the offset from its own clock,
storing the difference with the card holder's account
information (for example in the database 411). Then when a
credit card issuer desires to validate a timestamp created by
the credit card, it may simply add the timestamp to the
offset stored with the card holder's account and then compare
the result against its own clock. If the time falls within a
specified time window then the timestamp should be considered
valid.

In order for the credit card issuer to verify a single-use
credit card number, it must know to which account the credit

card number belongs. Instead of encoding the account number
as part of the credit card number, the name that appears on
the card could take the place of the account number. In that
case every credit card must have a different name printed on
the card. The trade-off in this instance is that many more
bits become available in the credit card number since they
are not used to encode the account number. They can then be
used to encode a timestamp, purchase information, or even
merchant information.

Second Embodiment (Lists of Single-Use Credit Card Numbers)

In this embodiment, the device memory 104 includes a database
with a list of single-use credit card numbers and a flag for
each number indicating whether the number has already been
used. The single-use credit card numbers are assigned to the
cardholder by the credit card issuer.

One method to assign single-use credit card numbers is as
follows. There are 2^{53} possible credit card numbers. Some
sort of central authority could assign ranges of account
numbers to individual credit card companies. Once a company
receives an r-bit range of account numbers they can further
split the range of numbers up however they please.
Ultimately, the credit card company would decide upon the
size of the nonce (N bits), the account number (A bits), and
the size of the IV (m bits) so that n+a+m = r. The account
number would include those bits assigned by the central
authority. Also, different card holders can have different
values of n, a, and m even if they received their cards from
the same credit card company. It is simply up to the company
to keep track of the appropriate information.

After a card holder's card expires their account number can be reused. The next credit card issued with that account number should use a different nonce and private key. This will ensure that any credit card numbers generated with the old credit card will not match any new credit card numbers with better than random chance.

The steps for obtaining a single-use credit card number according to this embodiment are shown in Figure 10. In step 1001, the cardholder enters his unique identifier (for example, a PIN or biometric data) into the device. The device determines whether the identifier is valid for the device (step 1002); if not, access to the device is denied (step 1004). If the identifier is valid, the device searches the single-use credit card number database in the device memory 104 for a single-use credit card number (step 1003). If a single-use credit card number is available (step 1005), it is displayed on the device display screen 102 (step 1007); if not, a message is displayed instructing the cardholder to obtain a new device (with a new list of single-use credit card numbers) from the credit card issuer (step 1006). The database in the device memory 104 is then updated to change the status of the number from "not used" to "used" (step 1008).

A schematic diagram of the credit card issuer's central processor according to this embodiment is shown in Figure 12. The processor 1200 includes a central processing unit (CPU) 1201. The CPU is connected to a clock 1202, a random-access memory (RAM) 1203, a read-only memory (ROM) 1204, and a communication port 1206 for communication with the merchant's central processor, similar to the first embodiment. In addition, the CPU 1201 is connected to a data storage device 1210, which includes a credit card account holder database

1211, a credit card number database 1212, and a credit card transaction database 1213. The credit card account holder database 1211 has the same structure as database 411.

The fields of the credit card number database 1212 are shown in Figure 13. Each cardholder account number 501 is associated with the cardholder name 502 and a list of credit card numbers 1301; each credit card number has associated therewith its status 1302 (used or not used).

The fields of the credit card transaction database 1213 are shown in Figure 14. Each record of this database corresponds to one transaction using the card, and includes the account number 501, the expiration date 507 of the card, the transaction amount 702, and the merchant identification number 703.

The steps for generating an authorization code for a credit transaction in this embodiment are shown in Figures 11A and 11B. In step 1101, the cardholder provides the merchant with a single-use credit card number displayed on the device (see step 1007 of Figure 10). The merchant then transmits the single-use credit card number and the transaction amount to the credit card issuer's central processor 1200 (step 1102). The central processor searches the credit card number database 1212 to identify the account holder of the transmitted single-use credit card number (step 1103), and determines whether the transmitted credit card number matches a credit card number listed in the credit card number database (step 1104). If there is no match, the credit card number is considered invalid, and the transaction is aborted (step 1105). If there is a match, the credit card number is considered valid, and the central processor checks the status 1302 of the credit card number to determine whether the

credit card number has already been used (step 1106). If so, the number is no longer valid, and the transaction is aborted (step 1107).

If the cardholder's account meets the credit card issuer's approval criteria (step 1121), then the issuer's central processor generates an authorization code and transmits the code to the merchant (step 1123). If not, the transaction is aborted (step 1122). Finally, in step 1124, the issuer's central processor changes the status 1302 of the credit card number from "not used" to "used."

While the present invention has been described above in terms of specific embodiments, it is to be understood that the invention is not limited to the disclosed embodiments. On the contrary, the present invention is intended to cover various modifications and equivalent structures included within the spirit and scope of the appended claims.